NASA TECHNICAL MEMORANDUM

NASA TM X-68133

NASA TM X-68133

A SINGLE-AXIS ELECTROSTATIC BEAM DEFLECTION SYSTEM FOR A 5-CM DIAMETER ION THRUSTER

by Walter C. Lathem
Lewis Research Center
Cleveland, Ohio

September 1972

This information is being published in preliminary form in order to expedite its early release.

A SINGLE-AXIS ELECTROSTATIC BEAM DEFLECTION SYSTEM FOR A 5-CM DIAMETER ION THRUSTER

by Walter C. Lathem

Lewis Research Center

SUMMARY

A single-axis electrostatic beam deflection system has been tested on a 5-cm diameter mercury ion thruster at a thrust level of about 0.43 mlb (25 mA beam current at 1400 volts). The accelerator voltage was -500 volts. Beam deflection capability of $\pm 10^{\circ}$ was demonstrated. A life test of 1367 hours was run at the above conditions. Results of the test indicated that the system could possibly perform for upwards of 10,000 hours.

E-7129

INTRODUCTION

Increasing emphasis on orbiting spacecraft for Earth resources studies, meteorology, navigation, and communications is planned in the 1970's. Many of these satellites will have stringent, long duration stationkeeping and attitude control requirements. As satellite lifetime increases, the ion thruster becomes an increasingly competitive alternative to cold gas and chemical type thrusters. The Lewis Research Center is working on a 5-cm Kaufman thruster with the durability (lifetime) and specific impulse to meet this satellite need. The Lewis 5-cm thruster program (both in-house and contract) has been described in references 1 and 2.

Recent development of ion thrusters with beam deflection capability enhances their usefulness because they can perform both stationkeeping and attitude control functions. Hughes Research Laboratories personnel

investigated several techniques for varying the thrust direction of a mercury bombardment ion thruster under Contract NAS3-14058. The results of this contract are described in references 3 and 4. A follow-on contract NAS3-15385, is in progress to further develop the 5-cm diameter electrostatic system. Additional testing was performed at Lewis on the two-axis electrostatic system and the grid-translation system (references 5 and 8).

An alternate electrostatic design with only single-axis beam deflection capability was designed and fabricated under the above contract and delivered to Lewis untested. This paper presents the results of subsequent testing of this system at Lewis.

APPARATUS AND PROCEDURE

A photograph of the deflection system as delivered to Lewis Research Center is shown in figure 1. The accelerator grid consists of a series of bars alternately attached to two sets of holders. A potential difference can thus be applied between bars on opposite sides of each screen aperture. The beam emerging through each aperture will be deflected toward the bar which is more negative.

Because of uncertainty concerning the end effects of this type of geometry, four different end terminations were built into the system. These types are more easily seen in figures 2 and 3. The bottom four apertures, as viewed in the figures, include additional accelerator segments intended to match the rounded ends of the screen apertures. Also the right ends of all nine screen apertures have a thin mask attached to the upstream surface of the screen grid. The radius of curvature of the mask apertures matched that of the end of the screen aperture (see fig. 1). All dimensions of this optics system are shown in table I.

Beam deflection was accomplished by setting the potentials of the accelerator bars so that one side of each aperture was more negative

and the other side less negative than the nomianl operating accelerator potential. The total difference between the potentials of the accelerator bars is referred to herein as the deflection potential. This procedure maintains the average potential in the aperture at accelerator potential. The deflection supplies were reversible in polarity. Current meters were provided in each supply to monitor changes in accelerator drain current under deflection conditions.

During operation the beam downstream of the thruster was scanned with a number of small probes of known cross-sectional area and the beam current intercepted determined by measuring the voltage across a resistor. The matrix of current density values thus obtained were then used to produce cross-sectional profile maps of the total thruster beam. This technique has been used extensively and has been described in previous works (refs. 1 and 3 to 7). Ion beam deflection angles were then determined by comparing similar points on profiles taken at the same distance downstream of the thruster for both deflected and undeflected modes.

All tests were done using a 5-cm thruster discharge chamber made from designs produced under Contract NAS3-14129 and described in reference 9. Minor changes were made to adapt Lewis type hollow cathodes for both the discharge chamber and the neutralizer. The tests were performed in a 1.5 m diameter by 4.5 m long vacuum facility (ref. 10). Vacuum was maintained at about 1×10^{-6} torr throughout the test.

RESULTS AND DISCUSSION

Performance Tests

At the time the test was started, a thrust level of 0.4 - 0.5 mlb was chosen. At a 25 mA beam current, a net voltage of 1400 volts gives a thrust of 0.43 mlb. A negative voltage of about -200 volts was

required to prevent electron backstreaming. The negative voltage was set conservatively at -500 volts to allow the beam deflection voltages to be set at values at least up to ±300 volts without electron backstreaming. Accelerator currents were typically about 70 μA. The discharge chamber was not optimized for this grid set prior to the test, but for the record, the propellant utilization efficiency was about 67 percent and the discharge losses were about 700 eV/ion.

A typical beam profile is shown in figure 4 as an equal current density contour map. The decimals on the figure represent fractions of the maximum probe signal. Notice that the beam spreads more in the direction perpendicular to the strip apertures. This same result was found for a cesium strip contact ionization thruster (ref. 11). The probe signals were taken with the probe in a plane 10 cm axially downstream and parallel to the plane of the accelerator grid. Similar profiles were taken for a range of applied beam deflection voltages. By examining the apparent displacement of similar points on the profiles, it was possible to determine the average angle through which the ions have been deflected. The resulting beam deflection angles are plotted against the applied voltage in figure 5. A deflection voltage of 380 volts was required to obtain 10° deflections angles. This voltage is approximately 20 percent of the 1900 volt total accelerating voltage (net accelerating voltage, 1400 V and average accelerator electrode voltage, -500 V). For deflection angles less than 10°, the rise in accelerator current was less than 5 percent.

LIFE TEST

A total of 1367 hours running time was accumulated on the single-axis electrostatic deflection system. The voltages were held constant at V_I = 1400 volts and V_A = -500 volts. The beam was deflected only long enough (about an hour total) to obtain deflection data.

The beam current was mistakenly held between 26 and 30 mA with

the typical value being 27 for about 500 hours because of a system measurement error. A review of the data uncovered this error and the operating conditions were readjusted to give the desired 25 mA beam current. Consequently, the test was run for an additional 867 hours with the beam current ranging from 24 to 27 mA.

A time plot of the ratio of the accelerator current to beam current is shown in figure 6. Two curves are indicated because of the two different operating beam current levels. If the beam current had been held at the lower operating level for the entire test, the ratio would probably have started somewhat below the upper curve and decreased to the final level of 0.0015.

The accelerator current observed in this test was caused by a combination of charge-exchange ions and primary beam ions striking the accelerator grid. During the course of the test the primary ions eroded material from the downstream edges of the accelerator bars. As the test progressed, this erosion caused a decrease in the number of primaries striking the grid so that the final level of accelerator current is believed to be mostly charge-exchange ions.

The accelerator erosion mentioned above was documented at specific points in the test schedule by stopping the test for a few hours and photographing and taking measurements of the grid erosion. Measurements of erosion were taken at the ends of every aperture. Erosion occurred only on the downstream edges of the accelerator bars and was greatest near the ends of the apertures. This data is summarized in table II and in figure 7, which shows the erosion depth in mils as a function of location number. Each of the data symbols represents one of the four quadrants of the grid (see inset) and the location numbers represent points on either side of each aperture counting inward from the edge aperture to the center aperture (see fig. 1).

Results of these tests indicate that the designer of this type of grid should include end terminations for the accelerator apertures. A further reduction of erosion can be obtained by masking off a short portion of the screen aperture. No effort was made to optimize the geometry of

either the accelerator or screen apertures. Additional improvements should be gained by further optimization.

Selected representative points of the most severe erosion are plotted in figure 7. The quadrants and location numbers marked on the curves correspond to those in figure 1. Note that the locations exhibiting the highest ultimate erosion also exhibited shorter leveling off times. Curve A-1 leveled off in the first 200 hours while curves C-1 and D-1 still exhibit some erosion activity at 1400 hours. Curve A-1 represents the worst case for lifetime considerations.

Because the accelerator currents had leveled off early in the test, it can be concluded that the initially high direct ion impingement does not represent a destructive mode for the accelerator. After 1367 hours it was difficult to determine the amount of erosion caused by charge exchange because no observable patterns had developed. Much longer duration tests would be necessary to determine the ultimate life capability of this accelerator system. However, it appears that if the best of the four types of aperture terminations were used, the lifetime should be greater than 10,000 hours.

CONCLUDING REMARKS

A single-axis electrostatic beam deflection system has been tested on a 5-cm diameter mercury ion thruster. It performed well at a thrust level of about 0.43 mlb (25 mA beam current at 1400 volts). The accelerator voltage was -500 volts. Beam deflection capability of $\pm 10^{\circ}$ was demonstrated with negligible rise in accelerator drain current.

A life test of 1367 hours was run at the above conditions. Considerable primary beam ion interception by the accelerator was noticed in the first few hundred hours. This caused erosion of the downstream edge of the accelerator strips which had leveled off after about 500 hours. Erosion caused by charge exchange ions was almost imperceptible. It was concluded that if the best of the four types of aperture terminations

were used, the system could possibly perform for upwards of 10,000 hours, although additional testing would be required for corroboration.

REFERENCES

1. Reader, Paul D.; Nakanishi, Shigeo; Lathem, Walter C.; and Banks, Bruce A.: A Submillipound Mercury Electron Bombardment Thruster. J. Spacecraft Rockets, vol. 7, no. 11, Nov. 1970, pp. 1287-1292.

2. Nakanishi, S.; Lathem, W. C.; Banks, B. A.; and Weigand, A. J.: Status of a Five-Centimeter-Diameter Ion Thruster Technology Program. Paper 71-690, AIAA, June 1971.

3. Collett, C. R.; King, H. J.; and Schnelker, D. E.: Vectoring of the Beam from Ion Bombardment Thrusters. Paper 71-691, AIAA, June 1971.

4. King, H. J.; Collett, C. R.; and Schnelker, D. E.: Thruster Vectoring Systems. Part I: 5 cm Systems. Hughes Research Labs. (NASA CR-72877), 1971.

5. Lathem, Walter C.: 1000-Hour Test of a Dual Grid, Electrostatic Beam Deflection Accelerator System on a 5-Centimeter-Diameter Kaufman Thruster. NASA TM X-67907, 1971.

6. Lathem, Walter C.; and Hudson, Wayne R.: Operational Characteristics of a Translational Screen Grid Beam Deflection System for a 5-cm Kaufman Thruster. NASA TM X-68008, 1972.

7. Lathem, W. C.: Grid-Translation Beam Deflection Systems for 5-cm and 30-cm Diameter Kaufman Thrusters. Paper 72-485, AIAA, Apr. 1972.

8. Hudson, W. R.; Lathem, W. C.; Power, J. L.; and Banks, B. A.: Optimization of Electrostatic Dual-Grid Beam-Deflection System. NASA TM X-68096, 1972.

9. Hyman, Julius, Jr.: Design and Development of a Small Structurally Integrated Ion Thruster System. Hughes Research Labs. (NASA CR-120821), Oct. 1971.

10. Keller, T. A.: NASA Electric Rocket Test Facilities. Transactions of the Seventh National Symposium on Vacuum Technology. C. Robert Meissner, ed., Pergamon Press, 1961, pp. 161-167.

11. Lathem, Walter C.; and Staggs, John F.: Divergent-Flow Contact-Ionization Electrostatic Thrustor for Satellite Attitude Control and Station Keeping. NASA TN D-4420, 1968.

TABLE I. - SINGLE-AXIS BEAM-DEFLECTION

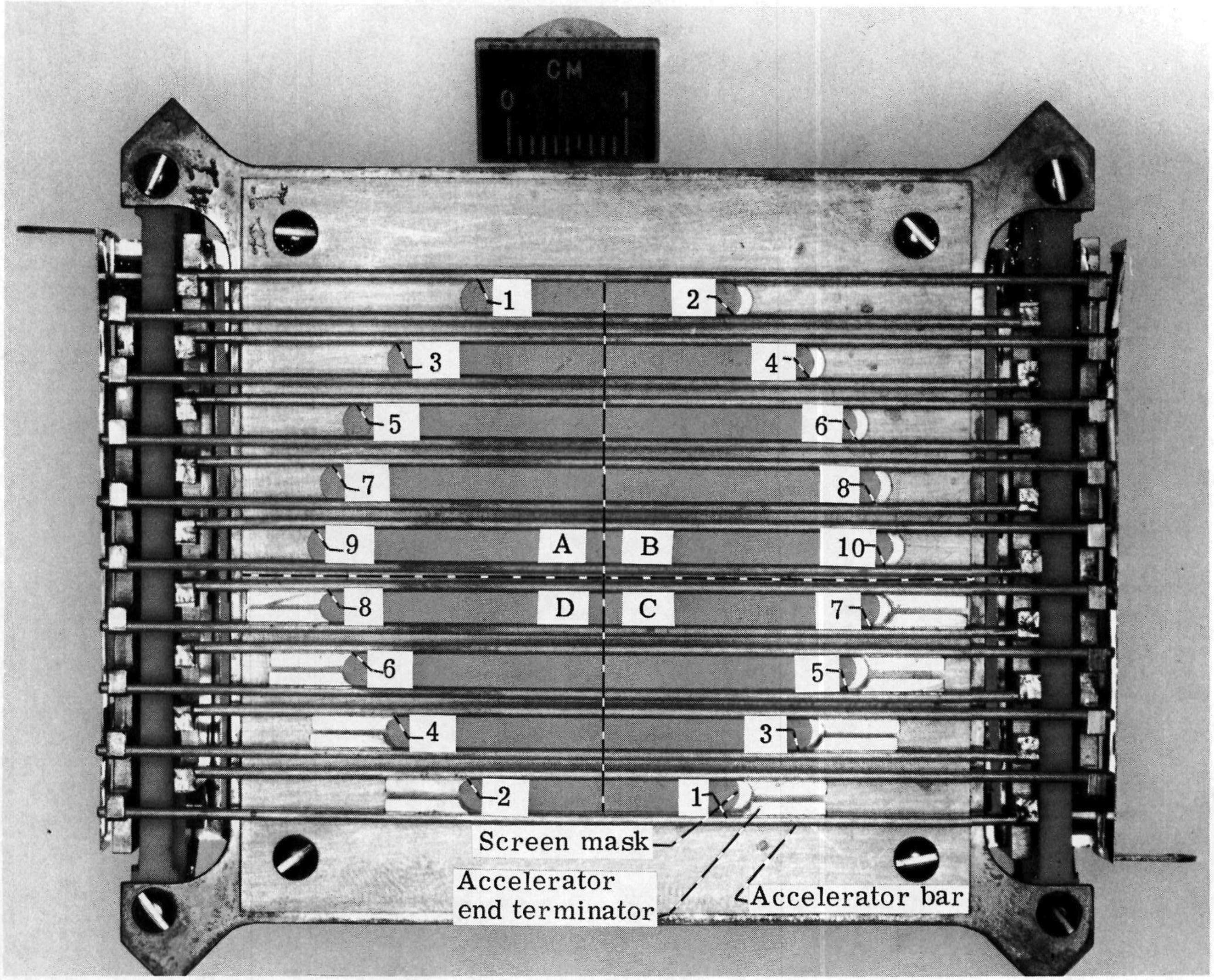
SYSTEM GRID APERTURE DIMENSIONS

	mm
Screen thickness	0.63
Screen mask thickness	0.076
Accelerator thickness	1.77
Screen aperture width	3.17
Accelerator aperture width	2.54
Grid-to-grid spacing	0.89
Aperture center-to-center spacing	0.53

TABLE II. - EROSION RESULTS FOR FOUR END-TERMINATIONS

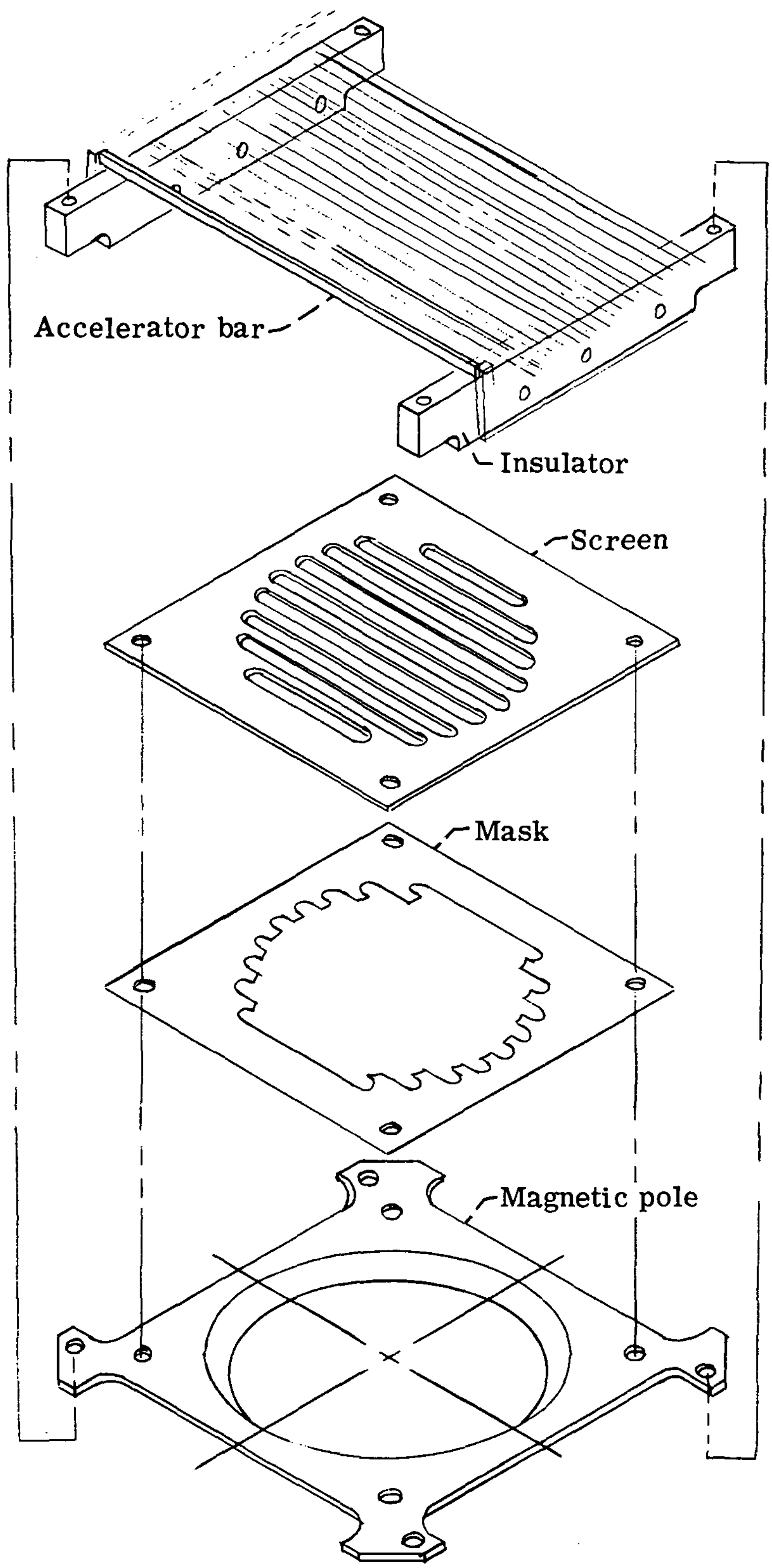
[Erosion depth in mils]

	Accelerator quadrant, (see fig. 1)	Location number									
		1	2	3	4	5	6	7	8	9	10
Mask and end terminations	C	5	3	8	2	3	3	3	3		
No mask but end terminations	D	5	3	15	2	5	5	8	5		
Mask but no end terminations	B	10	5	10	5	7	7	5	3	5	3
No mask and no end terminations	A	15	5	10	5	10	10	8	8	8	8



(a) Photograph of accelerator system.

Figure 1. - Single-axis electrostatic beam deflection system for a 5-cm diameter ion thruster.



(b) Exploded view of accelerator system.

Figure 1. - Concluded.

E 7129

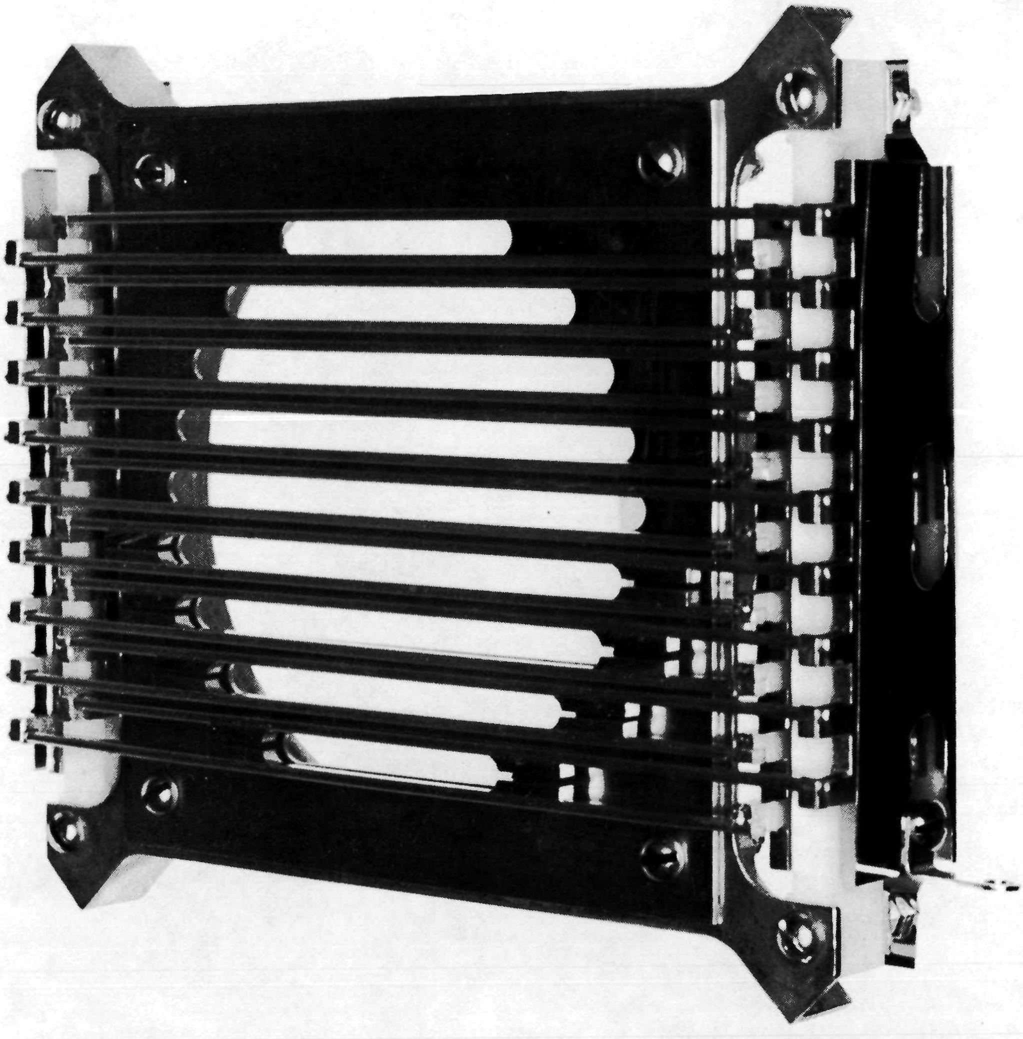


Figure 2. - Single-axis electrostatic beam deflection system for a 5-cm diameter ion thruster.

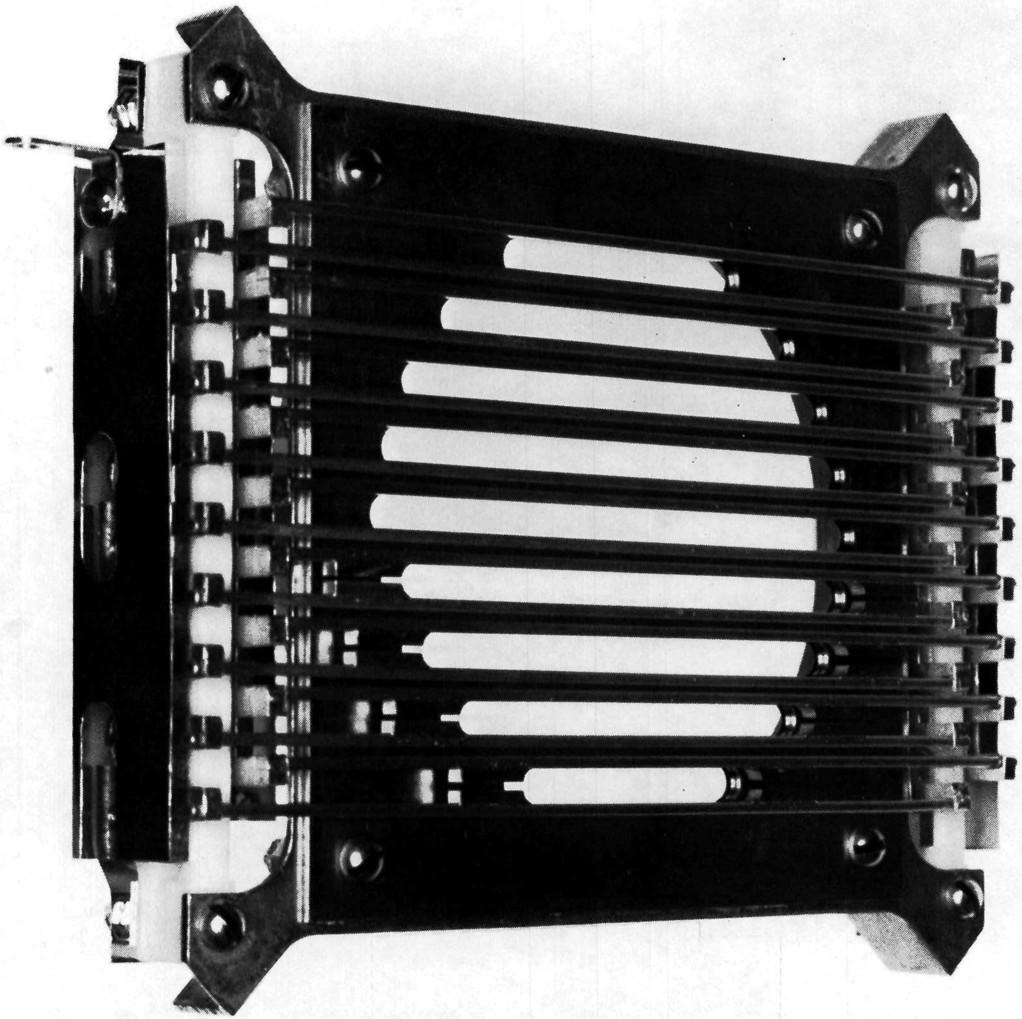


Figure 3. - Single-axis electrostatic beam deflection system for a 5-cm diameter ion thruster.

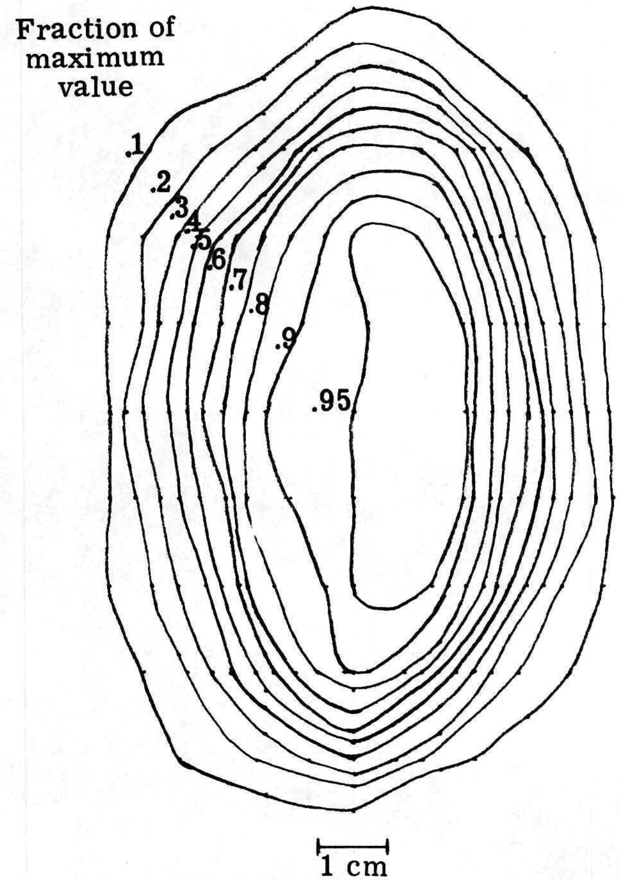


Figure 4. - Equal current density contour map 10 cm downstream of single axis electrostatic system. Apertures were horizontal.

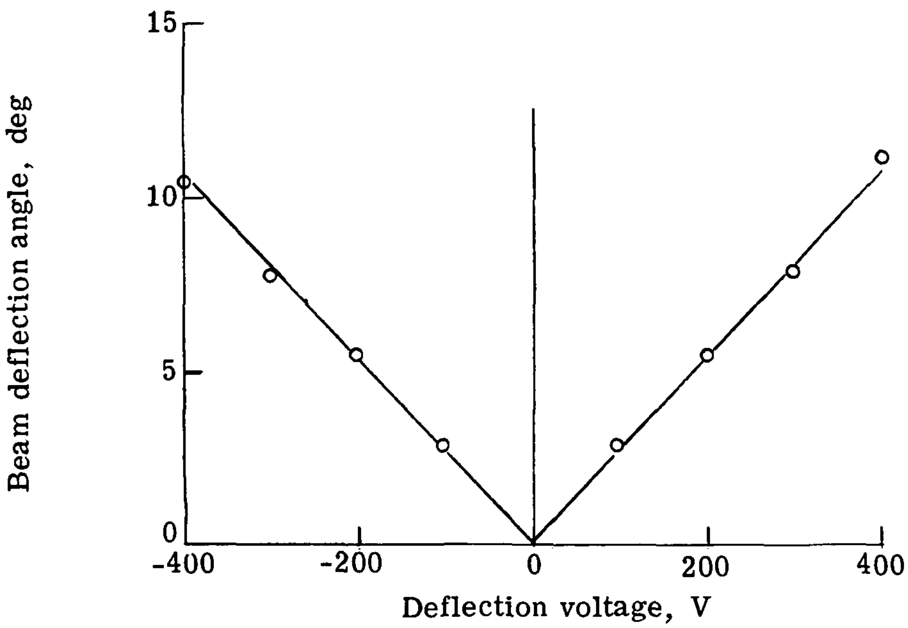


Figure 5. - Beam deflection angle versus deflection voltage for single axis electrostatic beam deflection system.

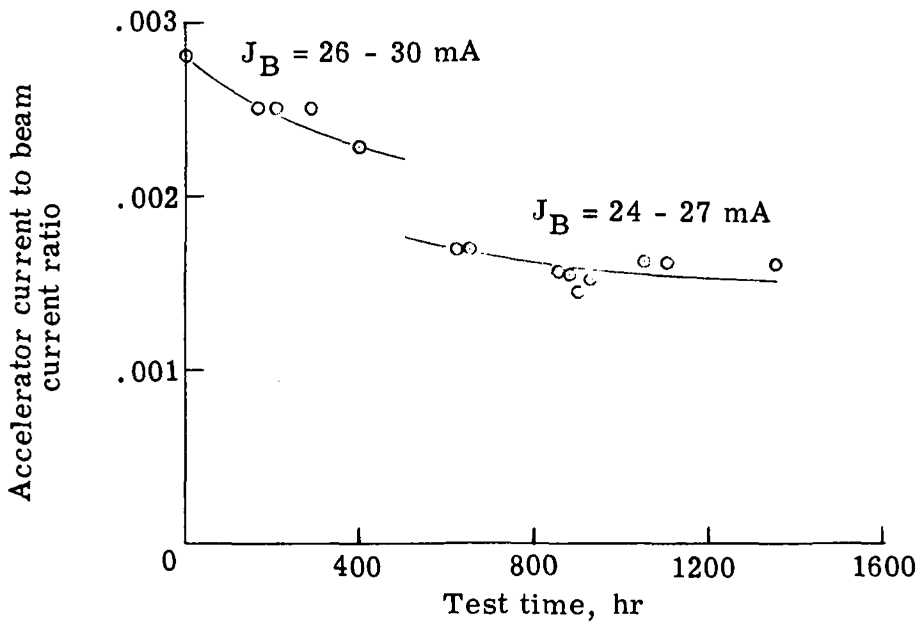


Figure 6. - Time history of the ratio of accelerator current to beam current.

E-7129

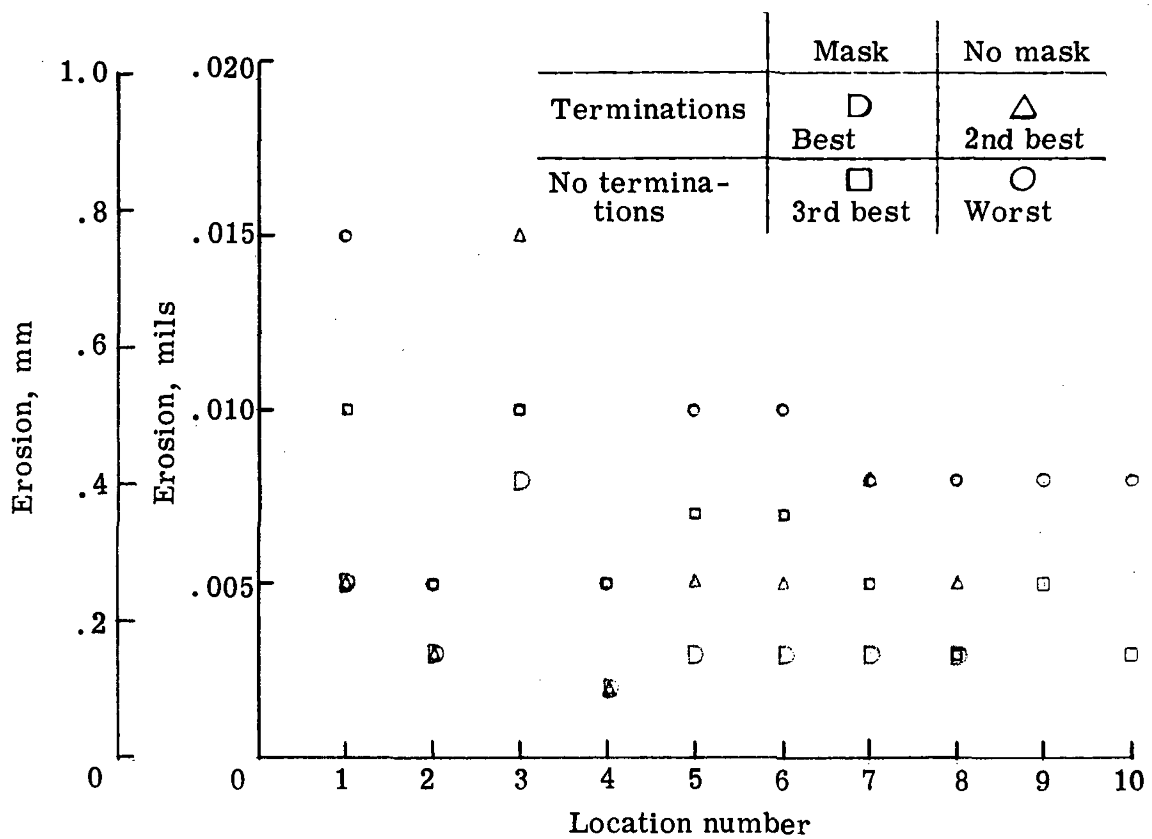
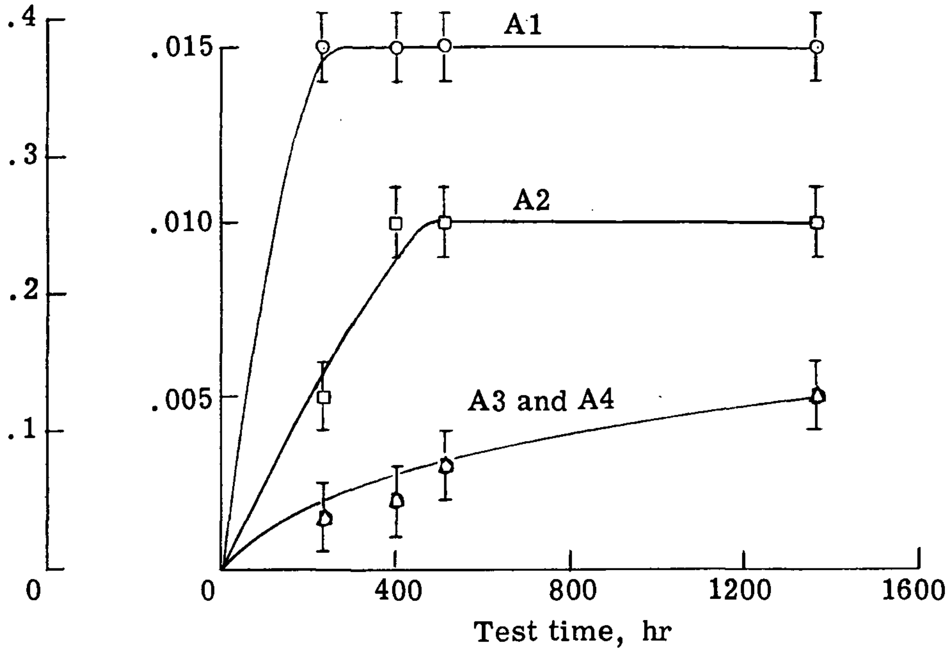


Figure 7. - Comparison of accelerator erosion for four types of aperture terminations (see table II and fig. 1).



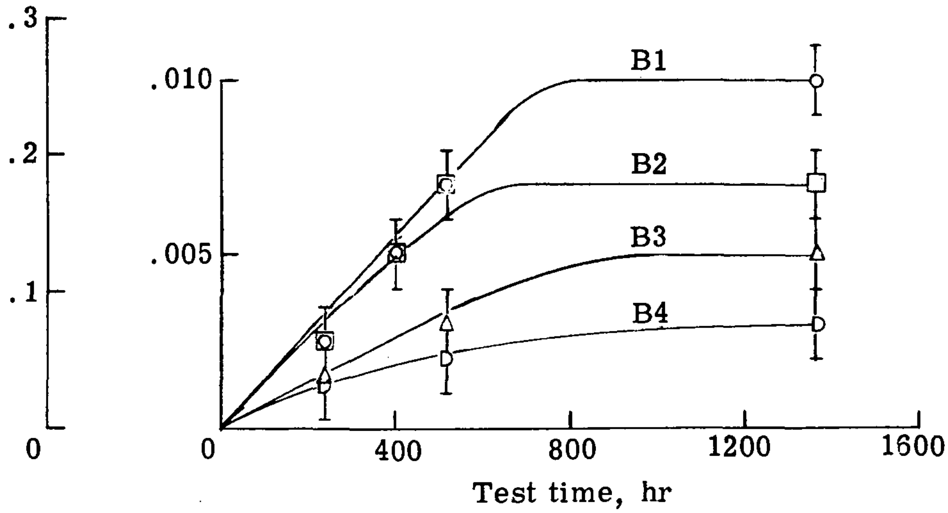


Figure 8. - Erosion of accelerator bars at points marked in figure 1.